

APPENDIX C

Work Breakdown Structure (WBS) and WBS Dictionary

NPDGamma PROJECT	
<u>1.0 EXPERIMENT</u>	<u>3.0 BEAM LINE</u>
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WBS DICTIONARY

[1.0 Experiment](#)

The experiment is the apparatus that will be used to measure the parity-violating gamma asymmetry from neutron capture by para-hydrogen. The apparatus has several components:

1.1 Signal Electronics

Gamma rays from the capture reaction are converted to light in CsI crystals. The light is detected by vacuum photo diodes in current mode. Currents from the photo diodes are amplified by low-noise and high-gain preamplifiers (WBS 1.1.3.2). Preamplifiers and low-noise power supplies (WBS 1.1.3.1) are mounted inside Al cases (WBS 1.3.3.109) that are attached to the CsI crystal housing. The differential and summing amplifier circuits (WBS 1.1.3.4) are also part of the signal processing.

WBS 1.1.2.5 Design of low-noise preamplifiers complete. Signal detection doesn't use PMTs, therefore high-gain and extremely low-noise preamplifiers are required. The completion of the element means that we have solved problems.

WBS 1.1.3.5 Preamplifier procurement complete. Assembly of 48-channel detector system can be started.

WBS 1.1.4.5 One signal channel working. Allows first time to see final signals from the detector. We can start to work with noise sources other than preamplifier noise.

1.2 Data Processing

After the preamplifiers, the signals are digitized by VME ADCs (WBS 1.2.3.4.1.4). Every preamplifier has its own ADC. Inside the experimental cave are two VME crates (WBS 1.2.3.4.1 and 1.2.3.5.1), one for the detector signals and another for other signals from the experiment. After the signals have been analog-to-digital converted, the VME will send them outside the cave through optical cables where signals are read by a VME unit and saved to data files for data analysis. Data can be accessed for analysis from outside the Laboratory.

WBS 1.2.2.2 DAQ first time functioning. We have written our own DAQ software. This was a proof of principle.

WBS 1.2.4.1 DAQ station #1 complete. The first out of three DAQ stations working.

WBS 1.2.3.1.3 VME station #2 complete.

WBS 1.2.3.2.2. VME station #3 complete. DAQ electronics complete

1.3 Detector

The detector consists of 48 crystals of thallium-doped CsI scintillators (WBS 1.3.3.1, 1.3.3.3, 1.3.3.4), each measuring 15 cm x 15cm x 15 cm. The crystals are arranged in 4 rings of 12 that surround the cryostat of the liquid hydrogen target. The scintillation light is converted to electrical currents by vacuum photo diodes (WBS 1.3.3.2 and 1.3.3.5), one per crystal. The detector array is supported by a stand (WBS 1.3.3.86) such that the housing of each crystal is electrically isolated from the others. Two LEDs are mounted on each crystal to allow testing with light pulses.

WBS 1.3.4.10 Submission of IUCF NSF proposal. This NSF funding is a part of the detector funding.

WBS 1.3.4.11 Submission of IUCF NSF MRI proposal. This is 80% of the funding of the 48 CsI crystals, the rest of the funding is covered by DOE capital funds.

WBS 1.3.2.2 Design of detector complete. Details of detector agreed.

WBS 1.3.3.4.2 Procure 10 CsI crystals. This is the LANL part of the crystal order. All the crystal specifications are agreed and the manufacturer of the crystals selected. Cost and delivery time are issues.

WBS 1.3.3.5.1 Indiana started CsI crystal procurement. Indiana was awarded the MRI. Delivery time of crystals is long.

WBS 1.3.3.6.1 Detector procurement complete. We have crystals and we can start testing of the full detector.

1.4 Polarizer

The neutron beam is polarized or its polarization analyzed by passing it through a glass cell of optically-polarized ^3He gas. Neutrons of one spin state are selectively absorbed by the ^3He . The ^3He is polarized by spin exchange with a small amount of laser-polarized rubidium vapor in the cell. The rubidium density is adjusted for optimum spin exchange by varying the temperature of the cell. ^3He polarization is monitored by NMR measurement.

WBS 1.4.1.10 Polarizer conceptual design completed. Polarizer specifications are defined.

WBS 1.4.2.12 Design of polarizer completed. The design for the polarizer exists and the polarizer has been integrated to the rest of the experiment.

WBS 1.4.3.2.8 NMR electronics procured. To procure the NMR electronics of the polarizer is the responsibility of a collaborator. The new approach for AFP – frequency sweep – is working.

WBS 1.4.4.3 First full sized sealed cell with long T_1 . The large polarization decay constant is the key for the maximum ^3He polarization. This milestone also means that we have a full size ^3He polarizer.

WBS 1.4.4.5.5. Construction and testing of additional sealed cells completed. Experiment has several working polarizer cells.

WBS 1.4.4.2 We have done the decision of sealed cell geometry. The final cell size and polarizer geometry agreed.

WBS 1.4.4.8 Working group decision for final polarizer. All the details of the polarizer specified.

WBS 1.4.4.9. Working group decision for laser system. Using high-power polarization test results we will use either broad- or narrowed band lasers

1.5 Flipper

The spin direction of the neutrons is rapidly reversed by the RF spin flipper. This device generates a time-varying solenoidal magnetic field along the beam direction but perpendicular to the neutron spin direction. This field when combined with the up-down DC guide field, rotates the neutron spins independent of neutron energy by 180 degrees. The spin direction can be selected for each neutron pulse by either turning on or leaving off the flipper.

WBS 1.5.1.3. Flipper conceptual design complete. Specifications agreed. We have some test results.

WBS 1.5.2.6. Flipper design complete. Design complete. Power RF switch problem solved. Spin-flip efficiency understood. RF shielding solved.

WBS 1.5.4.7. Spin flipper built. RF spin flipper complete.

1.6 Guide Field

A set of large current coils surrounds the entire apparatus to generate a 10 Gauss homogeneous magnetic field. This field establishes and maintains the polarization axis for the neutrons. The neutron spin direction is constrained to be parallel or anti-parallel to the guide field direction.

WBS 1.6.1.2. Field calculations completed. The geometry of the experiment agreed and the location of the cave steel walls agreed. The field homogeneity requirement understood.

WBS 1.6.2.4. Guide field design complete. Technical issues solved.

WBS 1.6.3.9. Guide field procurement complete. The Procurement is the responsibility of a collaborating institute. Schedule and costs are issues.

1.7 Target

The liquid hydrogen target consists of a cryogenic vessel (WBS 1.7.3.3) containing approximately 20 liters of liquid para-hydrogen, maintained at a temperature of 17 K. The target is cooled by a pair of closed-cycle helium refrigerators (WBS 1.7.3.1) and insulated from ambient temperature by a several layers of material separated by vacuum (WBS 1.7.3.2). The target is capable of liquefying hydrogen from a room-temperature gas and maintaining the hydrogen in a liquid state for long periods. The hydrogen target has to meet strict Laboratory safety requirements.

WBS 1.7.1.4. Review of conceptual target design and safety. The safety envelope for the LH2 target has been specified.

WBS 1.7.1.7. Collaboration meeting around the LH2 target. Responsibilities decided.

WBS 1.7.2.1.1. Target engineering design complete. Major engineering design ready for safety review.

WBS 1.7.2.7.1. Passed LH2 target design safety review. Fabrication of hardware can be started.

WBS 1.7.4.5. Target testing in Indiana completed. The target passed first tests.

1.8 Monitors

There are three neutron flux monitors. The first, placed at the exit of the neutron guide, and the second, placed after the ^3He polarizer, are transmission mode monitors (WBS 1.8.3.1 and 1.8.3.2). The third, placed after the target, stops the entire cold neutron beam (WBS 1.8.4.3). The combination of the three monitors provides continuous measurement of the neutron beam intensity and polarization, and indicates any changes in beam intensity, in target density or in the target ortho/para hydrogen ratio.

WBS 1.8.2.1.1. Monitor #1 design complete. Monitor #1 design meets specifications.

WBS 1.8.3.5. Monitor #1 delivered. Monitor #1 ready for beam tests.

WBS 1.8.4.2.1. Monitor #1 tested. Experiment has a working neutron monitor.

WBS 1.8.4.7. Back monitor ready. All the neutron beam monitors ready.

1.9 Cave

The cave consists of alternating layers of steel and regular and borated polyethylene to reduce the neutron radiation. The thickness of the shielding is defined by intensity of fast neutrons (1 keV-100 keV) and gamma rays. The facility requires that outside the shielding during the worst scenario situation, dose levels have to be less than 1 mrem/hr. In addition to the radiological shielding, the cave acts as a magnetic flux return for the cave and as a Faraday cage for the sensitive detector electronics. A door at the rear of the cave provides access to the experiment. Several neutron tight penetrations in the shielding walls are required.

WBS 1.9.1.6. Agree conceptual design of cave shielding. Shielding principle agreed.

MCNPX calculations performed. We know our cave size and how to get the experiment mounted.

WBS 1.9.2.8. Cave design complete. Major design effort over.

WBS 1.9.4.9. ER2 shielding installation started. Labor intense effort, has to be done in time.

1.10 ER-2 Utilities

The ER-2 utilities provide 480 V and 120/208 V three-phase power for electrical equipment located outside of the cave. In addition, a high-quality isolation transformer provides heavily-filtered 120/208 V three-phase power to the inside of the cave. An additional 120 V single-phase isolation transformer is used for each DAQ station.

WBS 1.10.1.2. Conceptual design of powering complete. The experiment requires more power than available in ER1 including special clean power. Requires careful design. To bring required power to the experiment can be costly.

WBS 1.10.2.2. Powering of experiment designed. Powering problems solved in budget and on schedule.

2 Beam Line

2.1 In-Pile

2.1.3.1 Thimble:

The thimble is a vacuum jacket that will isolate the guide vacuum from the spallation source cryo vacuum. It forms the boundary to the CAT III nuclear facility. The thimble has been built to fit precisely the existing FP12 liner inside the bulk shield.

2.1.3.9 In-pile guide:

Inside the bulk shield is a super mirror neutron guide with an inner cross section of 9.5cm by 9.5 cm. Because of the size of the FP 12 liner in the bulk shield, a novel method was developed to maximize the guide size. The ~~up~~downstream (?) half of the guide is cantilevered by the guide insert-

2.1.3.4 Guide insert:

The Guide insert holds and supports the in-pile glass neutron guide inside the bulk shield. The insert allows the guide to be aligned accurately. The guide insert supports guide in a novel way by cantilevering the guide-

2.1.3.6 Transporter:

To allow the precise installation of the 4-m long glass guide into the thimble, a special device, the transporter, was built.

WBS 2.1.2.7. Thimble designed.

WBS 2.1.4.2.1. Thimble installed into the bulk shield.

WBS 2.1.2.9. Guide insert&transporter design complete.

WBS 2.1.3.21. Thimble, insert, transporter fabricated

WBS 2.1.4.9.1 Transporter modifications finished. We have only one chance to test the transporter in ER1 before the shielding has to be restored for the beam. The transporter will be ready for the in-pile installation.

WBS 2.1.3.20. In-pile guide received. The in-pile guide is the most delicate component of the beam line. The delivery means the successful fabrication. The item will be on the site and ready for installation.

WBS 2.1.4.7. In-pile guide installed. The most delicate and complicated installation among the beam line components. The in-pile guide is the first beamline component to be installed. If we are successful the rest of the beamline work is mainly hard labor.

2.2 Shutter:

Next to the bulk shield is the shutter. The shutter has to stop the beam when in the closed position so that personnel can work in the experimental cave. In the open position, the neutron guide installed inside the shutter transmits neutrons to the rest of the neutron guide. The shutter position has to be interfaced to the facility interlocked personnel security system (IPSS) system. The shutter block is about 2 m long and weighs about 2.5 tons. It is moved by a hydraulic system. This shutter will be the first external shutter in the facility.

2.2.3.2 ER-1 Floor work:

The shutter and the neutron guide in ER-1 have to be isolated from the ER-1 floor. This is accomplished by cutting openings in the floor and installing support pillars on the base plate under ER-1.

2.2.3.4 Control electronics:

The shutter is part of the facility safety system. Control electronics is interlocked to the facility safety system. The control electronics have to be approved by the facility.

WBS 2.2.4.1.1. ER1 floor modifications complete. Shutter and guide have to be isolated from the vibrating ER1 floor that will be also distorted by heavy weight of shielding. The ER1 floor modifications have to be done during the facility maintenance break when in ER1 is heavy maintenance activities going on - good scheduling required. Floor ready for shutter and guide installation.

WBS 2.2.2.5. Shutter design complete. Decision was done that the design of the external shutter systems for flight paths 12 and 13 will be done in house. This would significantly reduce the costs of the shutter. The shutter design is the most complicated design effort done in house for the beam line. The completion of the shutter design is a significant achievement. The shutter design defines the front part of the integrated shielding.

WBS 2.2.3.6. Shutter fabrication complete. Schedule is tight. The shutter is ready for testing and commissioning.

WBS 2.2.4.8. Shutter complete. Shutter ready for beamline installation. Has to meet the schedule.

2.3 Chopper

The frame overlap chopper has two rotor wheels capable of rotating at 20 Hz in phase with the neutron beam pulses. The phase is measured for each beam pulse and corrected as needed. A portion of each wheel is coated with a gadolinium-bearing paint to absorb slow neutrons which would overlap with fast neutrons from the next pulse. The use of only one wheel is required for normal operation, allowing for greater reliability. Both wheels are operated for some diagnostic modes.

2.4 Integrated Shielding

Because of the close proximity of flight paths 11, 12, and 13 in ER1, it is necessary and cost effective to cover these beam lines with integrated shielding, instead of building individual shielding around the beam lines. Shielding is comprised by layers of steel, regular polyethylene and borated polyethylene. Shielding thickness/efficiency is defined by the facility. During the worst possible scenario, the dose rate (?) outside the shield has to be less than 2 mrem/hr. (?) (The specification given in 1.9 calls for half of this?)

2.5 Guide

The low energy neutrons are guided to the experiment by a neutron guide. The inner cross section of the guide is 9.5cm x 9.5 cm. This supermirror guide has the critical angle three times of that for ^{56}Ni . The 12-m long guide has three sections which have to be aligned very accurately. The whole guide system has to be isolated from floor vibrations.

2.6 ER-1 Utilities

Some modifications has to be done to the existing utilities in ER1. Some of the power and signal lines have to be removed to more convenient locations. The ER-1 utilities are derived from the ER-2 utilities and provide 480 V and 120/208 V three-phase power.

APPENDIX D

Gantt Chart

[insert Gantt chart pages here]

APPENDIX E

Work Package Dictionary

Work Package Structure of the Experiment:

Work package ID	Work package title
E1	DAQ
E2	Detector
E3	Polarizer
E4	Spin Flipper
E5	Guide Field
E6	LH2 Target
E7	Beam Monitors
E8	Cave
E9	ER-2Utilities

Identification number: E1.

Work Package Title: DAQ

Work Package Leader; S. Wilburn, LANL

Covers WBS elements: 1.1 and 1.2

Work Package Description:

A. Technical Content: This Work Package includes the vacuum photo diode readout electronics, difference and summing electronics, VME ADC modules, other VME modules, VME controller, VME computer, PC computer (UNIX platform), storage media, and the off line data analysis computer connected via Ethernet.

B. Specifications: Each CsI detector module has its own preamplifier. The preamplifier has to be capable of handling the large gamma flash at the beginning of the pulse and have a current noise of less than $40 \text{ pA}/(\text{Hz})^{1/2}$. Assuming the peak output of the vacuum photo diode about 0.1 mA, then the output voltage of the preamplifier shall be about 5V. The voltage noise at the input of the ADC has to be a few times the least bit resolution.

The VME ADC has to be capable of 10ms sampling with 16-bit resolution. VME computer has to be capable of transferring the data from the ADCs and other VME modules to the PC computer at the full expected data rate. Two PC computers are required. The first computer receives data from the VME crates via fiber optic Ethernet and sends the data to tape and to the second computer. The second computer provides online analysis and display capability. The data storage device must be capable of handling the full expected data rate and have a capacity of

5 TB. The offline data analysis computer must be capable of reading the stored data and performing the required calculations.

C. Schedule Content:

	Start	Finish
3" Hamamatsu photodiode selected		finished
1/3 scale DAQ tested in beam		finished
Photodiode preamplifier design		
VME operating system from pSOS to Linux	1/2001	5/2001
DC/DC power supply design	11/2000	6/2001
Photodiode housing design	11/2000	6/2001
DAQ with three VME crates	3/2001	8/2001
Data writing on tape and backup writing	3/2001	11/2001
Fabrication of detector housings	6/2001	1/2002
Production of 48 preamplifiers	8/2001	1/2002
Measurement of noise with 12 channels	1/2002	3/2002
Build the rest of 36 channels	1/2002	7/2002
Ready for data taking		9/2002
Prototype development		
Bench testing of preamplifiers		
Bench testing of diff/summing amplifiers		
Testing with beam		
Modifications		
Construction of 48 channels		

D. Cost Content:

WBS		\$k
1.1.3	Signal electronics procurement	35
1.2.3	Data processing procurement	70
1.1.4	Signal electronics fabrication	4
1.1.5	Signal electronics commissioning	1
1.2.5	Data processing commissioning	2

Identification number: E2

Work Package Title: CsI Detectors and Stand

Work Package Leader: M. Snow, Indiana

Covers WBS element 1.3

Work Package Description:

A. Technical Content:

CsI detectors and stand.

The experiment requires a gamma detector array for the 2.2 MeV gamma rays from the reaction $n+p \rightarrow D + \gamma$. The detectors in the array must absorb and contain 90% of the energy of the incident 2.2 MeV gamma and deliver enough scintillation light to produce at least 500 photoelectrons per gamma in a vacuum photodiode. The detectors must incorporate an external light source for calibration purposes. The overall detection efficiency of the array must be greater than 60% for the isotropic ($l=0$) component of the reaction and greater than 80% for the parity-odd ($l=1$) component. The segmentation of the array and the balance between the overall efficiency of the array elements must be fine enough to resolve parity-conserving asymmetries (L-R) from parity-violating asymmetries (U-D) and to assure that a L-R asymmetry is not seen as a U-D asymmetry at the 1% level. The stand that supports the array must possess sufficient adjustability to achieve these specifications.

The design of a 48-element array that satisfies all of these constraints exists. 4 prototype CsI crystals have been tested with gammas from neutron capture and shown to possess all required features, including sufficient output of photoelectrons from a vacuum photodiode coupled to the detector, sufficient gain stability to make possible the 1% efficiency matching of the detectors, and successful use of LED lights to perform calibrations. Monte Carlo simulations have shown that 4 layers of 12 cubic crystals of dimensions 15 x 15 x 15 cm satisfy the efficiency and gamma containment constraints.

B. Specifications:

CsI(Tl) crystals:

The experiment requires 48 CsI(Tl) crystals of dimension 15 x 15 x 15 cm with 3" windows for coupling to vacuum photodiodes. The detectors must be constructed of nonmagnetic components. LED inserts must be included in the housing to introduce calibration signals. The detectors must be encased in a dry environment and possess mounting brackets for mechanical connection to a stand.

Stand:

The stand must support 1 ton and allow the mechanical assembly of the CsI detector array in a modular fashion. The stand must be made of nonmagnetic components and allow adjustability

in x, y, and z directions. It must incorporate neutron shielding and electrical isolation. It must be large enough to accept the liquid hydrogen target vacuum vessel and the RF spin flipper.

D. Schedule Content

	Start	Finish
Procurement of CsI crystals	Aug-01	Apr-02
Procurement of stand materials	Sep-01	Oct-01
Procurement of neutron shielding	Dec-01	Apr-02
Testing of CsI crystals with photodiodes	Apr-02	Jul-02

D. Cost Content

WBS		\$k
1.3.2	Detector design	4
1.3.3	Detector procurement	586
1.3.5	Detector commissioning	5

Identification number: E3.

Work Package Title: ^3He Polarizer

Work Package Leaders: K. Coulter, UM, T. Smith, NIST

Covers WBS element 1.4

Work Package Description:

A. Technical Content: The experiment requires a polarized ^3He cell to work as a neutron spin filter. It will be placed in the guide field (E5) upstream of the spin flipper (E4). The primary component of the spin filter is a glass cell of ^3He that is polarized via spin exchange with optically pumped rubidium vapor. At present there are two conceptual designs for the ^3He spin filter cell. The first is a valved system with a small volume, high-density cell in which the ^3He is polarized (pump cell) and a large low-pressure cell through which the neutrons pass (target cell). ^3He is introduced into the pump cell, polarized, transferred to the target cell, and removed when a new batch is ready. The second design is a sealed cell in which either the ^3He polarization takes place in the same volume as the neutron polarization or there are separate pump and target cells which are diffusively connected. Each of these systems will include a pump cell oven to produce the required rubidium vapor pressure. These systems are under development at the University of Michigan and the National Institute for Standards and Technology, respectively. The decision on which system will be used will be made in January 2002.

Additional components of this work package are the ^3He NMR polarimetry, the optical pumping laser system, a cell heating system, and mechanical supports for the cell/oven and the NMR coils. The valved system also requires a ^3He supply and recovery system.

The current design for the laser system incorporates 3 to 4 high-power broadband laser diode arrays. Testing is being done of spectrally narrowed laser diode arrays. If these new lasers offer a substantial advantage, they will be incorporated. This decision will be made by January 2002.

B. Specifications: The ^3He target cell must provide a neutron polarization P_n and transmission I_n (relative to the entire FP12 beam) that satisfy the constraint of $P_n^2 I_n = 0.121$ for 4 meV neutrons. This corresponds to a target cell with a thickness of 5 amagat-cm (5 atmosphere-cm at 0°C or 1.1×10^{20} atoms/cm²) that covers the entire beam and has a time averaged ^3He polarization of 50%. However, this figure of merit may also be reached by a smaller area cell with a higher ^3He polarization. Cells must also demonstrate a working lifetime of at least one month. This means that they must operate at running temperature for one month period and be able to meet the $P_n^2 I_n$ specification at the beginning and end of the month. Valved cells must also be demonstrated a one month period, but with an appropriate number of gas transfers.

As a contingency for the possible failure of ^3He cells which meet the $P_n^2 I_n$ and lifetime specification there will be two sealed cells available for running, or two of each type of cell, pump and target, for the valved system. Loss of one of any of the cells during the experiment would prompt the working group to go back into production of another cell.

The ^3He NMR polarimetry system must be able to measure the ^3He polarization with a relative error of $<0.2\%$ and have polarization losses of $<0.5\%$. It should be calibrated prior to the data

run to better than 5% and will be calibrated via neutron transmission to better than 2%. It must also be able to effect on a ^3He spin flip with no significant change in the guide field.

The broadband laser system must provide ≥ 50 Watts of circularly polarized laser light to the ^3He cell centered at 795 nm with a spectral width of ≤ 2 nm. The narrowed laser system will need to produce higher ^3He polarization than the specified broadband lasers.

C. Schedule Content:

(Note that construction of ^3He cells will not necessarily continue once cells meet the NPDGamma specifications and contingency plans.)

	Start	Finish
Construction & testing of 4 sealed cells	Feb-01	Jun-01
Construction & testing of 3 valved cells 3 target and 3 pump	Feb-01	Jun-01
^3He gas handling and recovery design	Mar-01	Sep-01
NMR polarimetry components procurement	May-01	Jul-01
Construction & testing of 2 sealed cells	Jun-01	Oct-01
Construction & testing of 1 valved cell	Jul-01	Nov-01
Laser beam delivery system design (one for each system- valved and sealed)	Aug-01	Sept-01
NMR Polarimetry Electronics and Software Integration	Aug-01	Nov-01
Construction & testing of 1 valved cell	Nov-01	Jan-02
Construction & testing of 2 sealed cells	Nov-01	Jan-02
^3He gas handling and recovery construction	Nov-01	Mar-02
^3He working group decision on final cell design	Jan-02	
^3He working group decision on final laser system	Jan-02	
^3He cell and NMR coils mechanical support design and construction	Jan-02	Apr-02
Construction & testing of 2 sealed cells	Jan-02	Apr-02
Laser system components procurement (broadband or narrowed)	Jan-02	Feb-02
Laser system construction	Feb-02	April-02
^3He gas handling and recovery test (1 month)	Apr-02	Jun-02
NMR, laser, ^3He cell, (^3He has handling...) integration	May-02	Aug-02
Installation of ^3He system	Sep-02	Dec-02

D. Cost Content:

WBS		\$k
1.4.3	^3He polarizer procurement	235
1.4.4.	^3He polarizer construction/install.	11
1.4.5	^3He polarizer commissioning	4

Identification number: E4.

Work Package Title: Spin Flipper.

Work Package Leader: S. Wilburn, LANL

Covers WBS element 1.5

Work Package Description:

A. Technical Content: This work package includes the radio frequency RF spin flipper (RSF) and associated electronics.

B. Specifications: The RSF must be capable of reversing the spins of neutrons with energies of 0-100 meV in a DC magnetic field of 10 Gauss. The RSF will accept the entire neutron beam, with losses due to capture in the windows of less than 5%. The spin flip efficiency, averaged over the beam profile, must be >90% for neutron energies below 15 meV. The RSF and associated electronics must not introduce false asymmetries of $>10^{-10}$, either through electronic pickup or Stern-Gerlach steering of the neutron beam. The RSF must be capable of turning on and off each macropulse and must be capable of surviving pulse-to-pulse cycling for at least two years of operation.

C. Schedule Content:

	Start	Finish
Beam tests with prototype flipper	Nov-99	Oct-00
Commissioning of final flipper	Oct-02	Nov-02

D. Cost Content:

WBS		\$k
1.5.2	Flipper design	4
1.5.3	Flipper procurement	7
1.5.4	Flipper construction/installation	5
1.5.5	Flipper commissioning	1

Identification number: E5.

Work Package Title: Guide Field

Work Package Leader: R. Carlini, TJNAL

Covers WBS element 1.6

Work Package Description:

A. Technical Content:

A set of large current coils surrounding the entire apparatus to generate a 10 Gauss vertical magnetic field. The field is needed to polarize and maintain the ^3He polarization, to reverse the spin direction of the neutrons, and to maintain the polarization axis for the neutrons. The neutron spin direction is constrained to be parallel or anti-parallel to the guide field direction.

B. Specifications:

The 10-Gauss field has to reach from the ^3He polarizer to the ^3He polarization analyzer. The direction of the field has to be known with the accuracy of ____ rad. This requirement is challenged by the steel shielding of the cave. The homogeneity of the field around the ^3He polarizer has to be $\Delta B/B < \text{___ mGauss}$, in the beam volume inside the spin flipper $\Delta B/B < \text{___ mGauss}$, in the para-hydrogen target $\Delta B/B < \text{___ mGauss}$ and in the ^3He polarization analyzer volume $\Delta B/B < \text{___ mGauss}$. Stability of the field has to be better than x mGauss/hour.

The field value will be measured at several locations, and incorporated in the data stream.

The magnet power supply will be located inside the cave and will be remotely controlled via fiber optics.

The wire size of the windings has to be selected so that the coils generate no more than 1.5kW heat in the cave.

C. Schedule Content:

	Start	Finish
Prototype beam test	7/2/00	10/2/00
Field calculations	4/30/01	8/29/01
Guide field design complete	9/3/01	1/16/01
Procurement and construction	1/21/02	5/2/02
Testing of the components	3/1/02	9/29/02
Installation in cave	8/3/02	9/26/02
Commissioning	11/1/02	12/27/02

D. Cost Content:

WBS		\$k
1.6.2	Guide field design	15
1.6.3	Guide field procurement	22
1.6.4	Guide field construction/install.	9
1.6.5	Guide field commissioning	1

Identification number: E6.

Work Package Title: LH2 Target

Work Package Leader: M. Snow, Indiana

Covers WBS element 1.7

Work Package Description:

A. Technical Content: The experiment requires a liquid hydrogen target to observe the reaction $n+p \rightarrow D+\gamma$. The target and associated equipment must be made of nonmagnetic materials. It must not depolarize the neutrons before capture in the LH2. The target must capture at least 60% of the incident neutrons from the cold neutron beam under construction at LANSCE. The target must allow the 2.2 MeV gammas to escape the target with at least 90% efficiency. The target cannot produce extra noise in the gamma ray signal which is significant compared to the gamma counting statistics. The target must be composed of materials which do not produce systematic effects which could mimic the parity-violation signal. The target must be safe and in operation and obey the safety constraints as determined by LANL.

The target will be composed of liquid parahydrogen held at 17K to reduce orthohydrogen impurities that can lead to neutron depolarization. The target will be operated in a superheated mode to suppress the formation of bubbles. The target vessel will be composed of magnesium-rich alloys in critical areas where systematic effects due to polarized neutron capture are possible. The liquid hydrogen will be cooled and converted to the parahydrogen molecular state using two cryo refrigerators. The target vessel will be a cylinder 30 cm in diameter and 30 cm long. Monte Carlo calculations have shown that this target will capture 60% of the neutrons from the cold beamline under construction at LANSCE. The main vacuum of the cryostat will be jacketed with helium gas for all components inside the experimental cave. The target vessel will possess sufficient strength and gas conductance to withstand all accident scenarios. The design of the target and vacuum vessel and the documentation of its construction and operation will incorporate all of the safety devices and features required by LANL.

B. Specifications:

(1) Cryostat and Target;

The cryostat will consist of two cryo refrigerators. One refrigerator will accept hydrogen gas input. It will possess a catalyst for parahydrogen conversion. It will liquify the hydrogen and cool the target and the 77K radiation shield by thermal conduction. The other refrigerator will cool the second radiation shield directly outside the target to a temperature sufficient to ensure that there is no radiative heat leak into the target. The target vessel will consist of a welded Al assembly with a Mg entrance window and a plastic seal. ${}^6\text{Li}$ -rich shielding inside the target vessel will be used to reduce the fraction of polarized neutron capture on Al to a negligible level. The main vacuum vessel will be surrounded with a helium jacket to prevent air leaks into the target.

The outlet of the target vessel will be connected to a gas vent system required to vent the target in certain accident scenarios. The temperature, pressure, and liquid level of the hydrogen will be monitored and used for target control with feedback supplied by heaters.

(2) Gas Handling System and Control

A gas handling system will be located outside of the shielding hut. Hydrogen gas from a supply bottle will be purified and fed into the target at a controlled rate. The status of the target thermodynamic properties before, during, and after filling will be monitored continuously. During normal operation the information will be sent to a feedback system to maintain target temperature and pressure and to the DAQ.

<u>C. Schedule Content</u>	Start	Finish
Procurement of cryo-refrigerators	Jul-01	Aug-01
Safety review of target design	Aug-01	Aug-01
Procurement of vacuum vessel	Nov-01	Dec-01
Procurement of target vessel	Nov-01	Dec-01
Construct gas handling system	May-01	Nov-01
LH2 target stand	Jul-01	Nov-01
Construction of target at IUCF	Oct-01	Apr-02
Non-LH2 target tests at IUCF	Apr-02	Aug-02
Delivery of target to LANL	Aug-02	Aug-02
Commissioning of LH2 target at LANL	Sep-02	Nov-02
Facility safety review at LANL	Dec-02	Dec-02
Operation of LH2 target on LANSCE beamline	Dec-03	Mar-03

D. Cost Content

WBS		\$k
1.7.1	Target conceptual design	33
1.7.2	Target design	49
1.7.3	Target procurement	189
1.7.4	Target construction/installation	44
1.7.5	Target commissioning	7

Identification number: E7.

Work Package Title: Beam Monitors

Work Package Leader: S. Page, Manitoba

Covers WBS element 1.8

Work Package Description:

A. Technical Content: *Front and Back Neutron Beam Monitors.* The experiment requires precise beam monitors to measure the neutron flux at the entrance to the experiment and also downstream of the liquid hydrogen target. A further beam monitor will be needed for diagnostic tests and auxiliary measurements. With LND Inc., Oceanside NY, these monitors will be designed and fabricated. One monitor will be provided by Sept., 2001 for beam tests at LANL. A second monitor will be constructed during the winter of 2001-02, incorporating lessons learned from the beam tests. A third monitor (spare) will be constructed during 2002 to be available by the start of data taking on the new beam line.

The experiment requires a 'thick' dc coupled neutron beam flux monitor to be positioned downstream of the liquid hydrogen target. A multi-gap $^3\text{He}/\text{H}_2$ ionization chamber constructed by collaborators from Indiana University is planned to be used for this purpose. The $^3\text{He}/\text{H}_2$ chamber performed adequately during a test run at LANL in September 2000, but some improvements to reduce electrical noise and sensitivity to mechanical vibrations are desirable.

B. Specifications:

Front Monitor. The experiment requires two 'thin' neutron beam flux monitors for use in the experiment, plus one spare. The incident beam monitor(s) are to have a $10 \times 10 \text{ cm}^2$ active area, to absorb approximately 0.1% of the incident neutrons at 4 meV, to be dc coupled with a response time $< 0.1 \text{ ms}$, to contain a minimum of material and no magnetic components, to be insensitive to gamma rays, and to introduce minimal background in the experimental area.

Back Monitor. The existing $^3\text{He}/\text{H}_2$ ion chamber monitor will be refurbished as necessary at LANL during 2002. If it is deemed appropriate, this monitor may be replaced at a later date by an upgraded version similar in design to the incident beam monitors but absorbing a greater fraction of the neutron flux. This work package includes the design and construction of a new downstream monitor, if necessary.

C. Schedule Content:

	Start	Finish
Incident beam monitor #1 design	Feb-01	Jun-01
Incident beam monitor #1 procurement	Jun-01	Sep-01
Beam test of monitor #1	Sep-01	Dec-01
Incident beam monitor #2 and #3 procurement	Nov-01 Feb 02	Jan-02 May 02
Downstream beam monitor refurbishing	Jan 02	Apr 02
New down stream monitor if necessary, design	Jan 02	Apr-02
Procurement of new down stream monitor	May-02	Sep-02

D. Cost Content:

WBS		\$k
1.8.3	Monitor procurement	10
1.8.4	Monitor construction/installation	16

Identification number: E8.

Work Package Title: Cave

Work Package Leader: S. Wilburn

Covers WBS element 1.9

Work Package Description:

A. Technical Content:

The cave is formed by a radiological shielding consisting of alternating layers of steel and regular and Borated polyethylene to reduce dose rates from cold neutrons, fast neutrons, and gammas to levels that meet the facility requirements. In addition, the steel wall acts as a magnetic flux return yoke for the cave and as a Faraday cage for the sensitive detector electronics. A door at the rear of the cave provides access to the experiment. Several neutron tight penetrations have to be made on the walls and ceiling.

B. Specifications:

C. Schedule Content:

	Start	Finish
Conceptual cave design	Feb-01	Apr-01
Design complete	Jun-01	Sep-01
Shielding installation	Jun-02	Oct-02

D. Cost Content:

WBS		\$k
1.9.1	Cave conceptual design	24
1.9.2	Cave design	56
1.9.3	Cave procurement	383
1.9.4	Cave construction/installation	74

Identification number: E9.

Work Package Title: ER-2 Utilities

Work Package Leader: S. Wilburn

Covers WBS element 1.10

Work Package Description:

A. Technical Content: This work package covers the electrical utilities for the cave in ER-2 and for the chopper in ER-1.

B. Specifications: The electrical utilities must provide at least 15 kVA of 120/208 V service outside of the cave and 15 kVA of 120/208 V service inside of the cave. In addition, a 480 V 3-phase circuit is required for the chopper. The utilities inside the cave must be provided through an isolation transformer and be wired with isolated ground outlets. Line-cord powered isolation transformers must be provided for each of the three DAQ stations. The complete system will include electrical panels, transformers, and outlets.

C. Schedule Content:

	Start	Finish
Design complete	Apr-01	Jun-01
Power installed	Jul-02	Sep-02

D. Cost Content:

WBS		\$k
1.10.2	Design of ER2 utilities	7
1.10.3	Procurement of ER2 utilities	31
1.10.4	Construction/install. ER2 utilities	33

Work Package Structure of the Beam Line Construction:

Work Package ID	Work package title
BL1	In-Pile
BL2	Shutter
BL3	Chopper
BL4	Integrated Shielding
BL5	Neutron Guide
BL6	ER-1 Utilities

Identification number: BL1.

Work Package Title: In-Pile

Work Package Leader; D. Bowman, LANL

Covers WBS element 2.1.

Work Package Description:

A. Technical Content:

The in-pile part of the neutron transport system comprises the in-pile neutron guide, the steel insert to hold the guide and allow the guide alignment, and the thimble to isolate the crypt vacuum from the guide vacuum.

B. Specifications:

The thimble is a vacuum jacket that will isolate the guide vacuum from the spallation source crypt vacuum. Its mechanical strength has to meet nuclear facility category III requirements. The thimble has to be built to fit precisely the existing FP12 liner inside the bulk shield.

Inside the thimble is a steel insert that cantilevers a 4-m long super mirror neutron guide with an inner cross section of 9.5cm by 9.5 cm

C. Schedule Content:

Start

Finish

D. Cost Content:

WBS		\$k
2.1.2	In-pile design	115
2.1.3	In-pile procurement	407
2.1.4	In-pile construction/installation	14
2.1.5	In-pile commissioning	6

Identification number: BL2.

Work Package Title: Shutter

Work Package Leader; S. Penttila, LANL

WBS element codes: 2.2.

Element Task Description:

Technical Content:

Specifications:

The shutter has to stop the beam when in the closed position so that personnel can work in the experimental cave. In the open position, the neutron guide installed inside the shutter transports neutrons to the rest of the neutron guide. The neutron guide has to be in vacuum or filled with helium-4 gas. The shutter guide has to be aligned with the rest of the guide system. The shutter operation has to be reliable and the shutter guide has to meet the alignment requirement after few years of operation. The shutter position has to be interfaced to the facility interlocked personnel security system (IPSS) system. The shutter block is about 2 m long and weighs about 2.5 tons. It is moved by a hydraulic system. The shutter will be the first external shutter in the facility. The shutter and the neutron guide in ER-1 have to be isolated from the ER-1 floor. This is accomplished by cutting openings in the floor and installing support pillars on the base plate under ER-1. The shutter is part of the facility safety system. Control electronics is interlocked to the facility safety system. The control electronics have to be approved by the facility.

Schedule Content:

Start Finish

Cost Content:

WBS		\$k
2.2.1	Conceptual shutter design	8
2.2.2	Shutter design	14
2.2.3	Shutter procurement	93
2.2.4	Shutter construction/installation	30
2.2.5	Shutter commissioning	4

Identification number: BL3.

Work Package Title: Chopper

Work Package Leader: M. Leuschner, University of New Hampshire

WBS element codes: 2.3

Element Task Description:

A. Technical Content: This work package includes the two neutron beam choppers, their motors, housing and support, and the associated monitoring and control systems.

The experiment requires the accurate determination of the incident neutron energy at the target, which will be determined by time-of-flight. Since spatial overlap of neutrons from successive beam bursts obscures the neutron time-of-flight information, a beam chopper is required to remove the extreme high and low velocity components from each neutron beam burst.

B. Specifications: The chopper system consists of two notched rotors that, while spinning, intersect the beam line and alternately transmit or absorb neutrons. The rotors can be operated individually or together to create angular aperture sizes between zero and 200 degrees.

Due to restricted access in ER-1, the rotors must be able to operate without maintenance for long periods of time. Each rotor must rotate at 20 Hz with a stable (programmable) phase relative to the proton beam burst (t_0). Each rotor must be able to automatically recover from phase errors caused by variations in the proton beam pulse period. These pulse period variations have been observed to be as large as 100 microseconds.

C. Schedule Content:

	Start	Finish
Conceptual design		Feb 2000
Purchase Motors (2x) and controllers		May 2000
Engineering evaluation		Oct 2000
Purchase motor hardware/software accessories		Dec 2000
Mechanical design	Oct 2000	Apr 2001
Control & monitoring design	Feb 2001	Apr 2001
LANSCE Review		May 2001
Machining of support & housing	Jun 2001	Jul 2001
Machining of chopper rotors	Jun 2001	Jul 2001
Assembly		Aug 2001
Balancing of rotors		Aug 2001
Control & monitoring assembly	May 2001	Sep 2001
System tests	Oct 2001	Dec 2001
Delivery of completed system to Los Alamos		Jan 2001
Installation at Los Alamos		Feb 2002

D. Cost Content:

WBS		\$k
2.3.1	Conceptual chopper design	3
2.3.2	Chopper design	61
2.3.3	Chopper procurement	51
2.3.4	Chopper construction/installation	3
2.3.5	Chopper commissioning	4

Identification number: BL4.

Work Package Title: Integrated Shielding

Work Package Leader; S. Penttila, LANL

Covers WBS element 2.4.

Work Package Description:

A. Technical Content:

B. Specifications:

Because of the close proximity of flight paths 11, 12, and 13 in ER1, it is necessary and cost effective to cover these beam lines with integrated shielding, instead of building individual shielding around the beam lines. Shielding is comprised by layers of steel, regular polyethylene and borated polyethylene. Shielding efficiency i.e. thickness of shielding layers is defined by the facility. During the worst possible scenario, the -dose [rate](#) outside the shield has to be less than 2 mrem-[/hr](#).

C. Schedule Content:

Start

Finish

D. Cost Content:

WBS		\$k
2.4.1	Conceptual shielding design	104
2.4.2	Shielding design	51
2.4.3	Shielding procurement	260
2.4.4	Shielding installation	51

Identification number: BL5.

Work Package Title: Neutron Guide

Work Package Leader; S. Penttila, LANL

Covers WBS element 2.5.

Work Package Description:

A. Technical Content:

B. Specifications:

The low energy neutrons from the moderator are transported to the experiment by a neutron guide. The inner cross section of the guide is 9.5cm x 9.5cm. This supermirror guide has a critical angle three times that of ^{56}Ni . The 12-m long guide has three separate sections which have to be aligned very accurately. The whole guide has to be in vacuum and it has to be isolated from floor vibrations.

C. Schedule Content:

Start Finish

D. Cost Content:

WBS		\$k
2.5.1	Conceptual guide design	12
2.5.2	Guide design	47
2.5.3	Guide procurement	585
2.5.4	Guide installation	11

Identification number: BL6.

Work Package Title: ER-1 Utilities

Work Package Leader; S. Penttila, LANL

Covers WBS element 2.6.

Work Package Description:

A. Technical Content:

B. Specifications:

Some modifications have to be done to the existing utilities in ER1. Some of the power and facility control signal lines have to be removed to more convenient locations. Our ER-1 beamline components will be powered from the ER-2 utilities especially 480 V and 208 V three-phase power.

C. Schedule Content:

2.6.2.3	Plans for ER1 modifications complete	Q3, 2001
2.6.4.3	ER1 modifications complete	Q4, 2001

D. Cost Content:

WBS		\$k
2.6.1	Conceptual design of ER1 utilities	2.3
2.6.2	Design of ER1 utilities	4
2.6.3	Procurement of ER1 utilities	14
2.6.4	Installation of ER1 utilities	27

APPENDIX F

DRAFT

Memorandum of Understanding between University of New Hampshire and Los Alamos National Laboratory

I. INTRODUCTION

This Memorandum of Understanding (MOU) outlines the activities that members of the University of New Hampshire (UNH) Nuclear Physics Group are carrying out in collaboration with Los Alamos National Laboratory Nuclear and Particle Physics Program (LANL NPP) as part of the NPDGamma collaboration. The purpose of the collaboration between these two parties is the construction of a *neutron beam chopper* that will be permanently installed on LANSCE flight path 12. The design and engineering studies of the chopper are being conducted in Los Alamos under the direction of Seppo Penttila and Scott Wilburn. The fabrication and testing of the chopper will be conducted in New Hampshire under the direction of Mark Leuschner. UNH will also design and implement the software and electronics systems required to operate it.

This document constitutes an understanding between UNH and LANL on the resources and time required to perform the work on the neutron beam chopper specifically. UNH expects to contribute to other parts of the experiment as well.

II. PERSONNEL

The time commitment of the UNH personnel is:

NAME	POSITION	2001	2002
Mark Leuschner	Research Assistant Professor	60%	60%
Mike Briggs	Graduate Student	25%	25%
Stephen Ketel	Undergraduate Student	75%	75%

III. COORDINATION AND RESPONSIBILITIES

Los Alamos personnel will be primarily responsible for the engineering design of the neutron beam chopper. LANL physicists Seppo Penttila and Scott Wilburn will serve as project liaisons for the UNH group.

The UNH members of the NPDGamma collaboration will participate in all aspects of the construction, testing, installation, and maintenance of the neutron beam chopper. Installation and maintenance will be coordinated through the proper Los Alamos channels.

IV. EQUIPMENT AND SERVICES PROVIDED

Subject to continued funding by external sources, the University of New Hampshire plans to:

- Provide the machining and assembly of the neutron beam chopper motor supports and rotor housing.
- Design and assemble peripheral electronic and software systems to operate the chopper.
- Execute the final testing of the completed system.
- Provide documentation specifying the design, operation, and performance of the finished system.
- Provide manpower for the installation and operation of the neutron beam chopper throughout the life of the NPDGamma experiment.
- Provide maintenance, in conjunction with Los Alamos, of the neutron beam chopper throughout the life of the NPDGamma experiment.
- Undergo required LANL safety and technical training to accomplish the above.

Los Alamos plans to:

- Undergo technical, cost, schedule and safety reviews as required.
- Provide the final mechanical design of the neutron beam chopper.
- Provide the Indramat motors and controllers.
- Fabricate and balance the rotors.
- Provide supervision, tools, supplies, and manpower for the installation of the finished chopper in the LANSCE beam line.

Specifications:

The chopper system consists of two notched rotors that, while spinning, intersect the beamline and alternately transmit or absorb neutrons. The rotors can be operated individually or together to create angular aperture sizes between zero and 200 degrees.

Due to restricted access in ER1, the rotors must be able to operate without maintenance for long periods of time. Each rotor must rotate at 20 Hz with a stable (programmable) phase relative to the proton beam burst (t_0). Each rotor must be able to automatically recover from phase errors caused by variations in the proton beam pulse period. These pulse period variations have been observed to be as large as 100 microseconds.

V. PLANNED FUNDING

UNH will provide funding and materials:

- To pay the salary and benefits of their personnel involved in this project.
- To machine the chopper motor supports and the rotor housing.
- To purchase the hardware and software accessories required for operation.
- To ship the completed system to Los Alamos.

Los Alamos will provide funding and materials:

- To acquire the Indramat motors and associated controllers.
- To machine and balance the chopper rotors.

Cost Estimate Summary:

Purchase of motors and controllers	LANL	\$15k	(completed)
Conceptual design	LANL	\$19k	(completed)
Evaluation of conceptual design	LANL	\$30k	(completed)
Final design	LANL	\$15k	(estimate)
Fabrication of motor support and rotor housing	UNH	\$20k	(estimate)
Rotors (machining)	LANL	\$7k	(estimate)
Rotors (Gd painting)	LANL	\$2k	(estimate)
Rotors (balancing)	LANL	\$1k	(estimate)
Software	UNH	\$1k	(quote)
Motor hardware accessories	UNH	\$6k	(quote)
Electronics	UNH	\$4k	(estimate)
Supplies	UNH	\$4k	(estimate)
Student Labor	UNH	\$4k	(estimate)
Commissioning	LANL	\$6k	(estimate)

VI. MILESTONE SCHEDULE

Feb 2000	LANL	Conceptual design complete
May 2000	LANL	Motors (2x) and controllers purchased
Oct 2000	LANL	Engineering evaluation complete
Dec 2000	UNH	Hardware and software accessories delivered
Feb 2001	UNH	Control & monitoring design
Apr 2001	UNH	Control & monitoring design complete
May 2001	UNH/LANL	Final design
May 2001	LANL	LANSCE Review
Jun 2001	UNH	Machining of support & housing
	LANL	Machining of chopper rotors
Jul 2001	UNH/LANL	Delivery of components
Aug 2001	UNH	Assembly complete
Aug 2001	LANL	Balancing of rotors
Aug 2001	UNH	Control & monitoring assembly

Dec 2001	UNH	Final system tests
Jan 2002	UNH	Delivery of completed system to Los Alamos
Feb 2002	LANL/UNH	Assembly
Mar 2002	LANL/UNH	Testing
Apr 2002	LANL/UNH	Installation (in ER1)
May 2002	LANL/UNH	Testing in beamline
Jun 2002	LANL/UNH	Commissioning

VII. SPECIAL CONSIDERATIONS

VIII. SIGNATURES

Dr. Mark Leuschner
Chopper Work Package Leader
Research Assistant Professor
University of New Hampshire

Dr. F. W. Hersman
PI, DOE contract DE-FG02-88ER40410
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